

June 3, 2004

Ken Zweibel  
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Golden CO 80401

**RE: NREL Subcontract # ADJ-1-30630-12**

Dear Ken:

This report covers research conducted at the Institute of Energy Conversion (IEC) for the period April 03, 2004 to May 03, 2004, under the subject subcontract. The report highlights progress and results obtained under Task 3 (Si-based Solar Cells) and Task 4 (Diagnostics).

**Task 3: Si Based Solar Cells**

In the previous report, results on the effect of Si/Al ration, annealing time and Al layer age on the grain size and fractional coverage of polycrystalline Si layers formed by in-situ MIC was summarized. It was found that increasing the Si/Al ratio and/or the annealing time either in the form of deposition time or post-deposition annealing led to greater fractional coverage. The effect of growth rate was not considered in that study where films were deposited at 1  $\mu\text{m/hr}$ . Thus, another set of Si films (HW 245) with thickness of 2-3  $\mu\text{m}$  was deposited at 5  $\mu\text{m/hr}$  on Al layers 100, 250, 500 and 1000 nm thick. The deposition temperature was 430°C. Figures 1a-d are optical micrographs taken through the glass substrate of the Si films deposited on the four thickness values of Al. The dark areas in the micrographs represent polycrystalline Si grains or film where grains have coalesced. Contrary to previous results at 1  $\text{m/hr}$  growth rate, the fractional coverage in this case increases with decreasing Si/Al ratio. The central area of the film on 500 nm Al, appears to have the densest coverage approaching 100%. The edge areas of this film had a fractional coverage resembling that of Figure 1b. However, after the 8 hour post deposition anneal at 500°C, the edge area had a fractional coverage similar to that in Figure 1c.

Such large gains in fractional coverage could not be achieved with films deposited at  $1\mu\text{m/hr}$ . Perhaps this could be explained by the nature of the Si layer deposited on the Al. At higher growth rates, it is conceivable that the Si films deposited were amorphous as a higher silane flow rate and lower residence time were used. Amorphous Si diffuses readily into Al and leads to complete MIC of the Si deposited. On the other hand, the microcrystalline, which, would result from lower deposition growth rates does not interact with Al at  $430^\circ\text{C}$  leading to incomplete MIC of the Si deposited. The films also had a significant number of cracks, which are visible in some of the micrographs. It is not clear at this point if this is the result of the higher deposition rates or of stress in the Al layers. Now that a continuous polycrystalline layer has been achieved (Figure 1c), electrical characterization of the layer will be carried out to determine its suitability for devices. In addition, the layers will also be used as templates for epitaxial growth of large grain I-layers. A poster titled “In-situ Aluminum induced Crystallization of Silicon Thin Films on Glass Substrates using HW-CVD” was presented at the spring 2004 MRS meeting in San Francisco. This poster and the accompanying manuscript summarized the most recent results of our work on the grain enhancement of HW-CVD Si films.

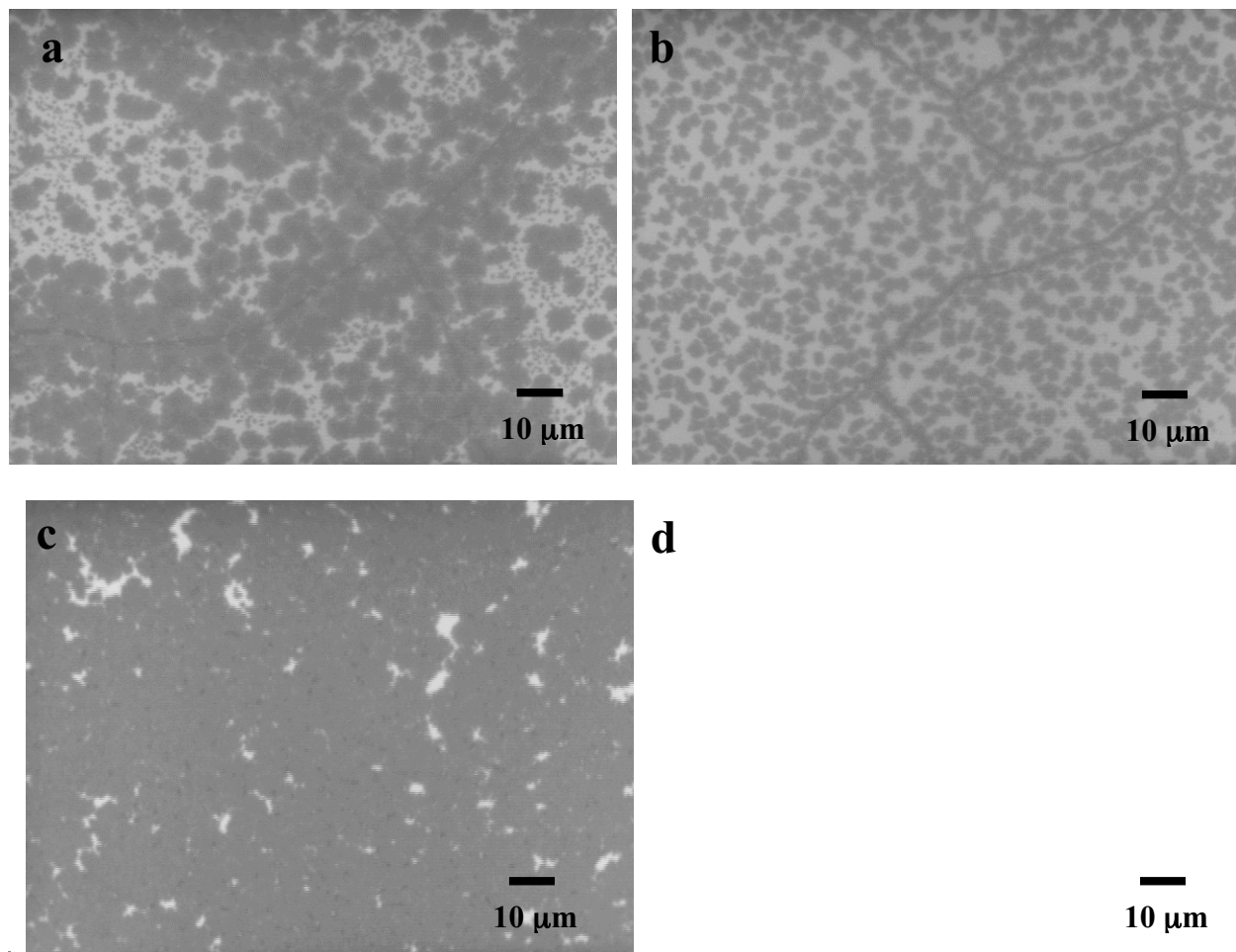


Figure 1. Optical micrographs through the glass substrate of deposited Si films on a) 100 nm, b) 250 nm, c) 500 nm and d) 1000 nm Al.

## Task 4 Diagnostics

A senior thesis titled “Contact Wetting Angle as a Diagnostic Tool for Analyzing the Surface Energies of ITO, CdS and CdTe Thin Films,” was completed in the Chemical Engineering Department at the University of Delaware by Michael S. Angelo, below is the abstract:

Contact wetting is a simple and effective probe for determining changes in the surface energies of indium tin oxide (ITO), CdS, and CdTe thin films resulting from post deposition processing at different stages during the fabrication of CdTe solar cells. The effects of processing on the energies, structures, and chemistries of these surfaces are analyzed and correlated.

Heat treatments of ITO at 500°C for 10 min. in atmospheres of air and Ar were found to crystallize surfaces and increase polar surface energies by 21.5 and 22.3 dyne/cm, respectively. Heat treatments with CdCl<sub>2</sub> to CdS at 400°C for 20 min. and annealing at 550°C for 10 min. were found to crystallize surfaces. CdCl<sub>2</sub> treatments were responsible for the most significant crystallization experienced by CdS films. Polar energies of CdS increased when heat treated with CdCl<sub>2</sub> and annealed by 25.6 and 17.6 dyne/cm, respectively.

CdCl<sub>2</sub> heat treatments in air at 400°C for 20 min. did not result in recrystallization of CdTe due to the initial thickness of the film (~3-4μm). Treatments created surface oxides and increased polar energies. CdO and CdTeO<sub>3</sub> were formed for samples that had been stored for 82 days at p<sub>H<sub>2</sub>O</sub> < 0.1 and 5 Torr. CdTe<sub>2</sub>O<sub>5</sub> was produced as a result of CdCl<sub>2</sub> treatments for the sample stored at p<sub>H<sub>2</sub>O</sub> 24 Torr. Polar energies for samples stored at p<sub>H<sub>2</sub>O</sub> < 0.1, 5 and 24 Torr increased by 9.8, 8.7 and 5.9 dyne/cm, respectively.

Etching CdTe in a solution of Br<sub>2</sub>:MeOH removed oxides that resulted from CdCl<sub>2</sub> treatments and decreased polar energies, but failed to completely remove CdTe<sub>2</sub>O<sub>5</sub>. The existence of this oxide for samples stored at p<sub>H<sub>2</sub>O</sub> 24 Torr affirms the necessity for low humidity storage environments for CdTe prior to CdCl<sub>2</sub> processing. Polar energies for samples stored at p<sub>H<sub>2</sub>O</sub> < 0.1, 5 and 24 Torr decreased polar energies by 4.4, 16.8 and 9.5 dyne/cm, respectively.

Sincerely,

Robert W. Birkmire  
Director

RWB/bj

Cc: Paula Newton

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Cc: Steven Hegedus